FROM "SEA ICE PROCESSES and Models" Edited by Robt S. Pritchard
Proceedings of the Arctic Ice Dynamics Joint Experiment, International Commission on Snow and Ice Symposium
U. of WASH PRESS / SEATTLE / LONDON 1980

A Long-Range Ice Forecasting Method for the North Coast of Alaska

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ABSTRACT

Observed relationships between April meteorological conditions in Siberia and the Alaskan Arctic and summer ice conditions in the shipping lanes along the north coast of Alaska are reported. An apparent natural cycle in the severity of year-to-year ice conditions is also described. A long-range ice forecasting method based on these relationships is introduced with an index which ranks the relative severity of ice conditions of each year since 1953.

INTRODUCTION

It has been a prevailing notion that summer sea ice conditions for most polar areas are predominantly dependent on summer environmental conditions, chiefly wind speed and direction and air temperature. The apparent futility of forecasting these weather conditions accurately in the long term has greatly inhibited research in long-range sea ice forecasting. In the navigation season of 1975, the collision of increased resupply activity and extremely severe ice conditions along the Alaskan North Slope generated a much greater demand for accurate long-range forecasts in that area. This paper summarizes the research done and the resultant long-range forecasting method developed to attempt to meet those demands.

DATA

Meteorological data used in the research were mean monthly 1000 mb charts produced by the Navy Fleet Numerical Weather Central, Monterey, California. Ice condition data were extracted from Naval Oceanographic Office annual ice reports for 1953–70 and from ice charts prepared by Fleet Weather Facility, Suitland, Maryland, for the period 1971–75. Significant data are detailed in Table 1.

The first step in the research was to rank the years by severity of summer ice conditions along the North Slope. The summers were ranked from 1 to 23 (1 being the mildest, 23 the most severe) for each of five parameters noted in Table 1. The cumulative ranking for each of the summers determined its position on the severity index. The parameters used to construct the index are chosen subjectively, but it is doubtful that another ranking technique would produce significantly different results. The four-eighths ice boundary was arbitrarily chosen as the division between conditions fairly easily navigable by unescorted vessels and those conditions posing a significant barrier. Obviously, four-eighths ice cover does present a threat and requires prudent operation. Conversely, unescorted navigation is sometimes possible in greater concentrations.

Columns 5 and 6 of Table 1 list the earliest date that Prudhoe Bay could have been reached from the west without encountering ice concentrations exceeding four-eighths and the date after which combined ice thickness and concentration would dictate the end of navigation. The terms opening date and closing date will be used interchangeably with these data although navigation can and occasionally does occur outside those dates (dependent on vessel class, availability and type of icebreaker support, determination, and necessity, as well as ice conditions). Note that 1975 is listed as never opening despite the partial success of a determined eleventh-hour entry. Canadian convoys enroute to the south central Beaufort Sea transited the North Slope shipping route several weeks prior to my defined opening date in both 1976 and 1977. As noted (+), the closing date in several of the pre-satellite years could not be determined because aerial reconnaissance stopped before freezeup. Conditions suggested by columns 7 and 8 were in many years intermittent through part or all of the season; the days therefore are not necessarily consecutive. Columns 9–12 are explained later in the text.

RESULTS

Significant differences were noted between April 1000 mb surface charts preceding favorable summer ice conditions along the North Slope and those preceding unfavorable* summers. The major notable difference was the strength and position of two pressure systems, the Siberian high and the Arctic high. April analyses preceding milder summers were typified by a relatively weak Siberian high and a strong high pressure system over the Arctic Basin (Fig. 1). April analyses preceding unfavorable summers were typified by a strong Siberian high

FAVORABLE
MILD
SUMMER
WEAK SIBERIAN
HIGH
STRONG ARCTIC
HIGH

*Unfavorable summers for the purpose of this study are those in which (a) the navigational season generally lasts less than 40 days, (b) the ice edge remains on the coast at Point Barrow throughout the season, or moves offshore intermittently 5–10 nautical miles at most, and (c) the heavy pack boundary (greater than four-eighths concentration) moves offshore later than 1 August and never moves northward far enough to relieve the potential danger. These seasons, in general, constitute the more severe half of the Severity Index.

UNFAVORABLE
STRONG SIBERIAN
WEAK ARCTIC
HIGH

2

Severity Rank = col's 2+4+7+8 + (No. of days btwn col. 5 and 1 Oct)

TABLE 1

Selected Sea Ice Data and Severity Index for the North Coast of Alaska, 1953–75

Severity Index	Year	1 nmi	2 nmi	3 nmi	4 nmi	5 Date	6 Date	7 # days	8 # days	9 Meters	10 Meters	11 Meters	12 Outlook	
1	1958	50	150	50	210	7/19	10/25	92	99	150	135	285	fav	
2	1968	25	165	30	200	7/19	10/18	86	91	160	115	275	fav	
3	1962	25	150	30	150	7/19	>9/30	49+	68+	165	100	265	fav	
4	1961	15	105	15	135	7/25	>9/24	49+	62+	125	130	255	fav	
5	1973	5	80	5	190	7/31	10/20	73	82	140	140	280	fav	
6	1954	20	115	20	210	8/1	>9/30	38+	61+	155	130	285	fav	
7	1959	20	65	20	65	7/19	10/6	42	86	135	115	250	fav	
8	1963	5	130	5	130	8/13	10/18	67	67	180	120	300	unfav	outlier
9	1972	0	60	30	90	7/31	10/1	45	63	165	105	270	fav	
10	1974	10	100	10	100	8/6	10/5	35	61	140	115	255	fav	
11	1957	5	45	70	60	8/1	10/6	18	67	150	105	255	fav	
12	1967	15	0	30	50	7/25	10/12	unk	68	175	100	275	fav	
13	1966	5	0	5	45	8/1	10/22	24	65	180	195	375	unfav	
14	1965	0	10	0	70+	8/25	9/25	25	32	180	120	300	unfav	
15	1953	0	0	5	35	7/27	>9/16	5	52+	180	150	330	unfav	
16	1971	0	0	0	30	8/23	11/1	8	71	160	135	295	unfav	
17	1960	0	0	20+	20	8/5	9/7	0	34	145	145	290	unfav	
18	1964	0	0	0	5	8/13	9/20	0	39	155	155	310	unfav	
19	1970	0	0	5	0	8/6	9/14	0	32	180	115	295	unfav	
20	1956	0	0	0	40	9/7	9/30	0	24	150	150	300	unfav	
21	1969	0	0	0	30	9/7	9/18	5	12	160	80	240	fav	outlier
22	1955	0	0	5	15	9/13	9/24	0	12	180	130	310	unfav	
23	1975	5	0	5	0	never	never	0	0	140	150	290	unfav	

Column 1: Distance from Point Barrow northward to ice edge (10 August).
Column 2: Distance from Point Barrow northward to ice edge (15 September).
Column 3: Distance from Point Barrow northward to boundary of four-eighths ice concentration (10 August).
Column 4: Distance from Point Barrow northward to boundary of four-eighths ice concentration (15 September).
Column 5: Initial date entire sea route to Prudhoe Bay less than/equal to four-eighths ice concentration.
Column 6: Date that combined ice concentration and thickness dictate end of prudent navigation.
Column 7: Number of days entire sea route to Prudhoe Bay ice-free.
Column 8: Number of days entire sea route to Prudhoe Bay less than/equal to four-eighths ice concentration.
Column 9: April mean 1000 mb height at point A (52°N, 100°E).
Column 10: April mean 1000 mb height at Point B (70°N, 140°E).
Column 11: Sum of columns 9 and 10 (A+B).
Column 12: Value in column 11 indicating favorable/unfavorable summer ($<$ 290 m = favorable; $\geq$ 290 m = unfavorable).

NOTE: Severity ranking is based on parameters in columns 2, 4, 5, 7, and 8.

NOTE: In several years, aerial ice reconnaissance was terminated before freezeup. The number of days in columns 7 and 8 is, therefore, indeterminable but slightly greater than listed, and is noted with a (+) sign.

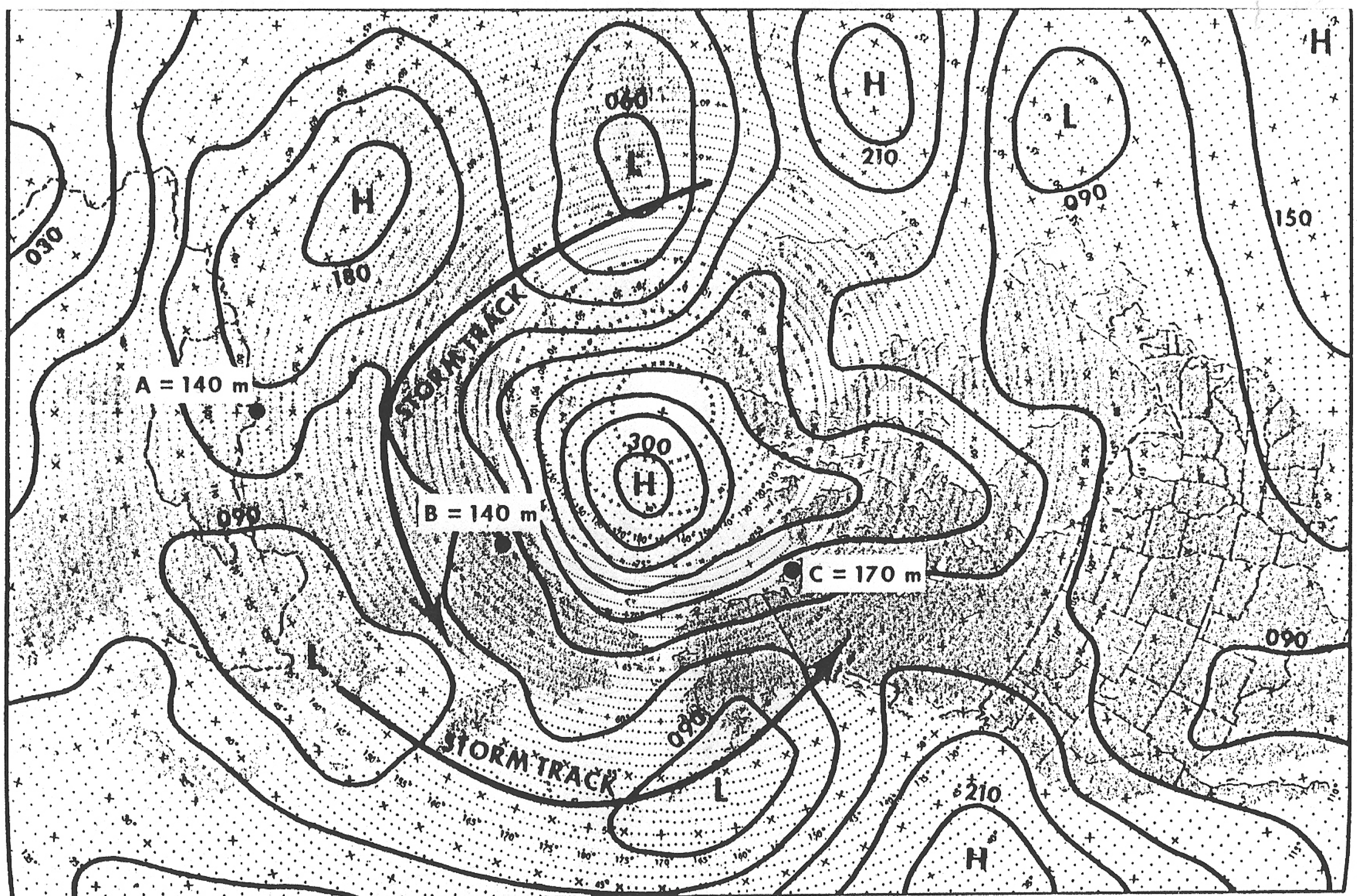

Figure 1. 1000 mb heights, in meters, April 1973.

FAVORABLE YR
mild summer sea ice conditions
WEAK SIBERIAN High & STRONG Arctic High

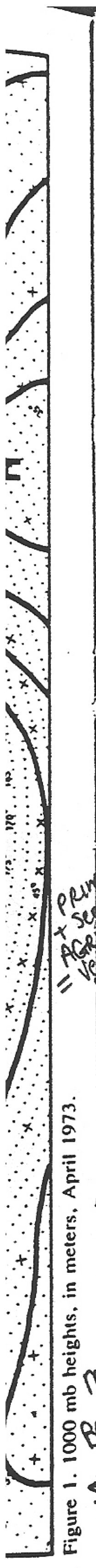

Figure 1. 1000 mb heights, in meters, April 1973.

and a displaced and generally weaker Arctic high (Fig. 2). Whether the strength or position of the Siberian high actually influences North Slope ice conditions was not determined. A strong Arctic high centered in the northern Beaufort and Chukchi seas would aid the westward and north transport of ice along the north coast. If these relationships are valid, a quantitative measure of the April strength and position of these pressure systems should produce a valuable long-range forecasting aid.

ARCTIC HIGH DIRECTLY INFLUENCES CONDITIONS

Further investigation did indeed suggest a strong relationship and show it to be measurable. April 1000 mb heights were extracted for a number of geographical points. Those indicated in Figures 1 and 2 were found to be the most useful: point A (52°N, 100°E), point B (70°N, 140°E), and point C (70°N, 130°W). Although the physical reasons are unclear, a correlation was discovered between the sum of April values at points A and B and the severity of ice conditions in the following summer. The sum is the prime indicator used in the forecasting technique. The relationship is presented in Table 2. A sharp difference can be noted in the severity of those seasons when this sum equaled or exceeded 290 m and those seasons when it was less than 290 m. After being categorized as favorable or unfavorable, however, the individual seasons are arranged nearly randomly within the category without respect to their prime indicator value.

* CUT-OFF POINT 290 M

PRIME A+B INDICATOR VALUE

FAV VS. UNFAV RANDOM LISTING IN COLUMNS

The predictability of the next season's position on the severity index can be improved by utilizing a secondary indicator, the 1000 mb height difference between point C and point A. Although not as consistently indicative (16 of 23 years) as the prime indicator, April C−A values of ≥ −10 generally preceded favorable summers. Lower values generally preceded unfavorable summers. Those years in which the prime indicator was supported by the secondary indicator in a favorable forecast averaged as more favorable than those in which the prime indicator's favorable forecast was opposed by the secondary indicator. This is more fully described below and displayed in Figure 3.

PRIMARY + SECONDARY AGREE = VERY FAV *

SECONDARY INDICATOR C-A

An investigation of similar pressure points in other months, January through May, uncovered no similarly significant ice predictors. Walsh (personal communication, 1976), who later correlated this severity index with monthly mean air pressures on a 5° latitude by 10° longitude grid extending from 60°N–90°N, 60°E–120°E, found selected July grid points to be the best single-month ice predictors, with April the second most predictive month and the only preseason month whose pressure patterns appear to correlate well with summer ice conditions.

JULY VS. APRIL

The reason for this strong correlation relative to surrounding months is uncertain. April, however, is the transition month between a strong winter Siberian high and the lower atmospheric pressures of late spring and summer. The sum of April 1000 mb heights at points A and B is therefore a measure of the timing of the seasonal breakdown of the Siberian high. This timing could perhaps be indicative of other atmospheric changes which influence or have already influenced large-scale ice movement in the Beaufort Gyre and the Transpolar Drift Stream.

MEASURE OF BREAKDOWN OF SIBERIAN HIGH *

6

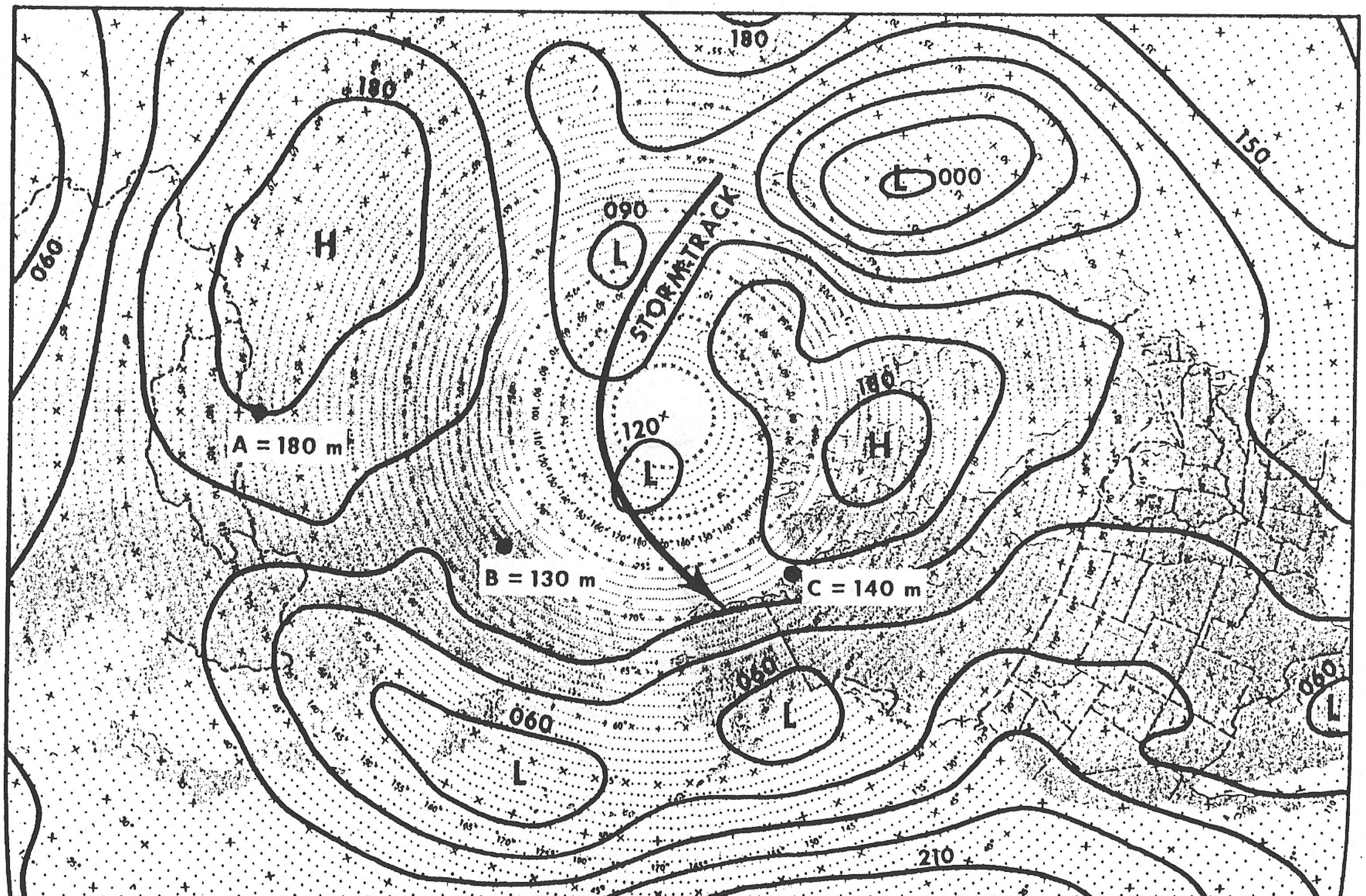

Figure 2. 1000 mb heights, in meters, April 1955.

UNFAVORABLE yr. Severe summer sea ice Conditions

strong Siberian High & displaced weak Arctic High

Barnett (1976) cautiously reported data which suggest the presence of a five-year cycle in North Slope ice conditions. Navigation conditions since 1955 have generally been least favorable in years divisible by five, most favorable the third year following those years (Table 3). It is now more strongly suggested that a natural cycle does exist, although one whose periodicity is not so rigid (Figure 3 shows a periodicity ranging from four to six years).*

WALSH SEVERITY INDEX

The severity index in Figure 3 is modified from the index in Table 1 by Walsh (personal communication, 1976). The index value for individual years is the sum of the numerical values in columns 2, 4, 7, and 8 of Table 1 plus the number of days between the date in column 5 and 1 October. This index has an advantage over the 1, 2, . . . , 23 ranking in Table 1 in that adjacent years in that ranking are not required to be evenly separated.

SPECIAL FEATURES

Several features are presented in Figure 3 that are believed to be significant. Ascending portions of the cycle usually span three or four years. These ascending portions strongly suggest that severe years leave a residual effect and that a recovery process is occurring, with the ice remaining from the previous season acting as a resisting force. Descending portions of the cycle span one or two years. The decline from a very favorable year can be more rapid as there is no resisting force. No further rise in a cycle occurs after an index value of 420 has been exceeded and no further decline in a cycle occurs after a value of less than 320 has been reached. Thus it may be possible in most cases to predict whether the cycle is at a maximum or a minimum.

As the degree of severity appears to be related to the severity of the previous year and to whether the cycle is in an ascending or a descending mode, the cycle is believed an essential input which can refine the forecast of the April 1000 mb indicators. For instance, ascending segments in years in which the prime indicator was favorable improved by an average of 257 index points when supported by a favorable secondary indicator. Improvement averaged only 114 index points when a favorable prime indicator was opposed by the secondary indicator, and only 44 index points when the prime indicator was unfavorable (the secondary indicator is not considered important in the latter case). Note that the only summer (1961) which improved significantly following a minimum (1960) is also the only year following a minimum in which both April indicators were favorable.

FORECAST METHOD

Table 4 outlines the long-range forecasts and verification data issued by the Navy Fleet Weather Facility in early May of 1976 and 1977. Using the above

*Rogers (1977) has recently presented evidence that summer air temperatures at Point Barrow, Alaska, correlate well with the severity index. Whether the relationship of summer temperatures to summer sea ice conditions is cause or effect can be debated, but the correlation in either case is not surprising. Rogers's spectral analysis of summer temperatures since 1921 shows a well-defined 4–5-year cycle since 1948, but he indicates that such a periodicity may have been less pronounced or even nonexistent before the late 1940s.

TABLE 2

COMPARISON OF SUMMER ICE CONDITIONS (NORTH COAST OF ALASKA) WITH APRIL 1000 mb HEIGHTS IN EASTERN SIBERIA

	1		2		3		4		5		6	
Year	≥290 m	<290 m	≥290 m	<290 m	≥290 m	<290 m	≥290 m	<290 m	≥290 m	<290 m	≥290 m	<290 m
1953	0		0		5		52+		35		7/27	
1954		20		115		38+		61+		210		8/1
1955	0		0		0		12		15		9/13	
1956	0		0		0		24		40		9/7	
1957		5		45		18		67		60		8/1
1958		50		150		92		99		210		7/19
1959		20		65		42		86		65		7/13
1960	0		0		0		34		20		8/5	
1961		15		105		49+		62+		135		7/25
1962		25		150		49+		68+		150		7/19
1963	5		130		67		67		130		8/13	
1964	0		0		0		39		5		8/13	
1965	0		10		25		32		70		8/25	
1966	5		0		24		65		45		8/1	
1967		15		0		unk		68		50		7/25
1968		25		165		86		91		200		7/19
1969		0		0		5		12		30		9/7
1970	0		0		0		32		0		8/6	
1971	0		0		8		71		30		8/23	
1972		0		60		45		63		90		7/31
1973		5		80		73		82		190		7/31
1974		10		100		35		61		100		8/6
1975	5		0		0		0		0		never	
Median	0	15	0	90	0	45	34	68	30	118	8/13	7/28

Column 1: Distance (nmi) from Point Barrow northward to ice edge (10 August).
Column 2: Distance (nmi) from Point Barrow northward to ice edge (15 September).
Column 3: Number of days entire sea route to Prudhoe Bay ice-free.
Column 4: Number of days entire sea route to Prudhoe Bay less than or equal to four eighths ice concentration.
Column 5: Distance (nmi) from Point Barrow northward to boundary of four-eighths ice concentration.
Column 6: Initial date entire sea route to Prudhoe Bay less than or equal to four-eighths concentration.

NOTE: Value is at left of column when the sum of the mean April 1000 mb heights at point A (52°N, 100°E) and point B (70°N, 140°E) was greater than or equal to 290 m, at right of column when it was less than 290 m.

NOTE: In several years, aerial ice reconnaissance was terminated before freezeup. The number of days in columns 3 and 4 is therefore indeterminable but slightly greater than listed, and is noted with a (+) sign.

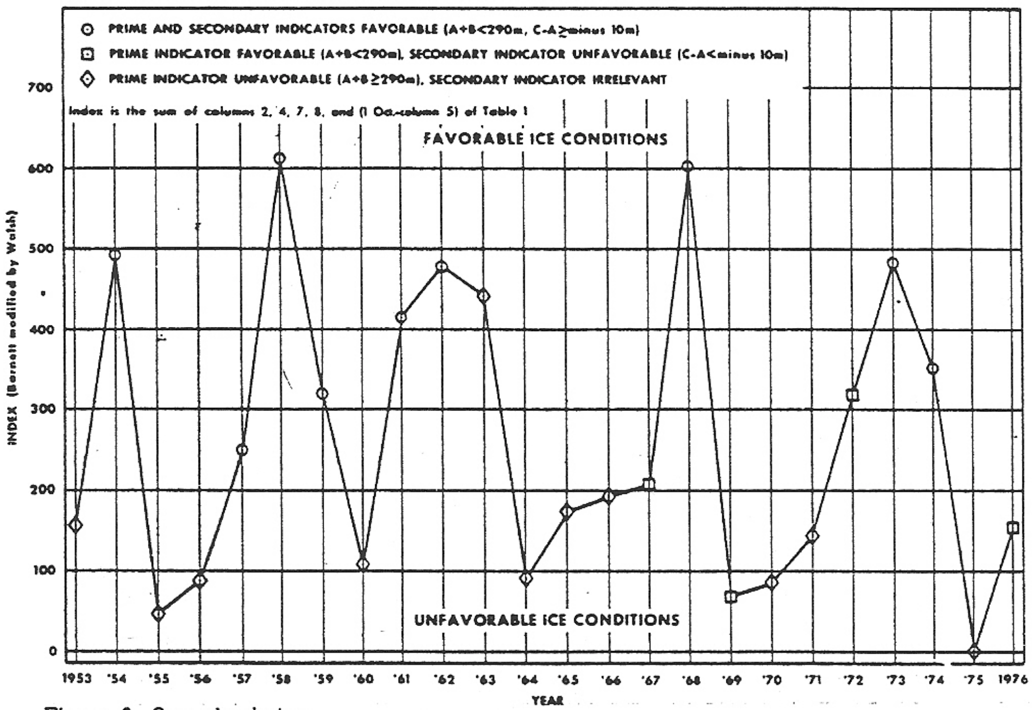

Figure 3. Severity index.

described techniques, a very simple several-step process produced these forecasts. First the April 1000 mb heights were computed for points A, B, and C. The values for A+B and C−A for April 1977 were 270 m (favorable) and minus 50 m (unfavorable), respectively. As noted above, an improvement of about 114 index points is expected over the previous year when a favorable outlook of the prime indicator (A+B) is opposed by an unfavorable secondary indicator (C−A). An index of 264 was therefore forecast for 1977 by adding that anticipated improvement to the 1976 index of 150. Since the previous year with an index closest to 264 was 1957, the forecast was further detailed by extracting significant data from the 1957 range (not necessarily that specific year) in columns 1 through 8 of Table 1. The 1976 forecast was prepared in a similar fashion.

CONCLUSION

Although initial energy has been directed toward quantifying the described relationships, there is yet a degree of subjectivity involved in this forecasting technique. A better understanding of the physical processes causing those relationships should yield improved results. Also, it is not suggested that those 1000 mb heights used are from the optimum geographical points, or that heights from two or three points in a single preseason month can adequately capture the total relevant pressure distribution. The data supporting a natural cycle indicate a

TABLE 3
CYCLIC PATTERN OF SEA ICE CONDITIONS ALONG THE NORTH COAST OF ALASKA, 1953–75

Year	1 nmi	2 nmi	3 nmi	4 nmi	5 # days	6 # days	7 Date
1953	0	0	5	35	5	52+	7/27
1958	50	150	50	210	92	99	7/19
1963	5	130	5	130	67	67	8/13
1968	25	165	30	200	86	91	7/19
1973	5	80	5	190	73	82	7/31
Mean	17	105	19	153	65	78	7/28
1954	20	115	20	210	38+	61+	8/1
1959	20	65	20	65	42	86	7/19
1964	0	0	0	5	0	39	8/13
1969	0	0	0	30	5	12	9/7
1974	10	100	10	100	35	61	8/6
Mean	10	56	10	82	24	52	8/7
1955	0	0	5	15	0	12	9/13
1960	0	0	20	20	0	34	8/5
1965	0	10	0	70	25	32	8/25
1970	0	0	5	0	0	32	8/6
1975	5	0	5	0	0	0	never
Mean	1	2	7	21	5	22	8/25
1956	0	0	0	40	0	24	9/7
1961	15	105	15	135	49+	62+	7/25
1966	5	0	5	45	24	65	8/1
1971	0	0	0	30	8	71	8/23
Mean	5	26	5	62	20	55	8/14

dependence of ice conditions on those in preceding years, but a knowledge of what triggers the reversals at the maxima and minima is needed.

Accurate longer-range forecasts may be possible utilizing other methods. For instance, the anomalous ice drift probably responsible for the very severe summers of 1955 and 1975 began at least 8–10 months prior to the navigation season. Lilly and Stewart (1977) have proposed a model which can issue a prediction of

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Mean	10	56	10	82	24	52	8/7
1955	0	0	5	15	0	12	9/13
1960	0	0	20	20	0	34	8/5
1965	0	10	0	70	25	32	8/25
1970	0	0	5	0	0	32	8/6
1975	5	0	5	0	0	0	never
Mean	1	2	7	21	5	22	8/25
1956	0	0	0	40	0	24	9/7
1961	15	105	15	135	49+	62+	7/25
1966	5	0	5	45	24	65	8/1
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Mean	5	26	5	62	20	55	8/14

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TABLE 3 (continued)

Year	1 nmi	2 nmi	3 nmi	4 nmi	5 # days	6 # days	7 Date
1957	5	45	70	60	18	67	8/1
1962	25	150	30	150	49+	68+	7/19
1967	15	0	30	50	0	68	7/25
1972	0	60	30	90	45	63	7/31
Mean	11	64	40	88	28	67	7/27

Column 1: Distance from Point Barrow northward to ice edge (10 August).
Column 2: Distance from Point Barrow northward to ice edge (15 September).
Column 3: Distance from Point Barrow northward to boundary of four-eighths ice concentration (10 August).
Column 4: Distance from Point Barrow northward to boundary of four-eighths ice concentration (15 September).
Column 5: Number of days entire sea route to Prudhoe Bay ice-free.
Column 6: Number of days entire sea route to Prudhoe Bay less than or equal to four-eighths ice concentration.
Column 7: Initial date entire sea route to Prudhoe Bay less than or equal to four-eighths ice concentration.
NOTE: In several years, aerial ice reconnaissance was terminated before freezeup. The number of days in columns 5 and 6 is, therefore, indeterminable, but slightly greater than listed, and is noted with a (+) sign.

TABLE 4
SEASONAL FORECASTS AND VERIFICATION DATA FOR NORTH COAST OF ALASKA

Forecast Parameters	Forecast 1977	Observed 1977	Forecast 1976	Observed 1976
Opening date, coastal route to Prudhoe Bay*	1–3 Aug.	2 Aug.	15–31 Aug.	15 Aug.
Length of navigation season	65–70 days	74 days	30–40 days	53 days
Number of days entire route is ice-free	30 days	63 days	0–5 days	21 days
Distance from Point Barrow northward to:				
Ice edge (10 Aug.)	10 nmi	5 nmi	0 nmi	0 nmi
Heavy pack edge** (10 Aug.)	25 nmi	25 nmi	0 nmi	0 nmi
Ice edge (15 Sep.)	25–30 nmi	55 nmi	0 nmi	15 nmi
Heavy pack edge** (15 Sep.)	60 nmi	85 nmi	30–40 nmi	15 nmi

*Opening date based on the initial date that the whole route to Prudhoe Bay may be navigated in less than or equal to four-eighths ice cover.
**Boundary between greater than four-eighths ice cover to the north, less than or equal to four-eighths to the south.